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(54) **SYSTEM AND METHOD OF MEASURING AND CONTROLLING TEMPERATURE OF OPTICAL FIBER TIP IN A LASER SYSTEM**

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(51) **Int. Cl.**
***G01K 11/00*** (2006.01)
***G01J 5/00*** (2006.01)
***H01S 3/13*** (2006.01)

(52) **U.S. Cl.** .................. **374/161**; 374/131; 372/38.01; 372/38.07; 372/29.02

(58) **Field of Classification Search** .................. 606/10, 606/11, 12, 15, 16; 374/161; 372/38.01, 372/38.02, 38.07, 29.02, 29.021, 32
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,374,328 A 2/1983 Tekippe et al.

(Continued)

FOREIGN PATENT DOCUMENTS

EP 1 088 523 A1 4/2001

(Continued)

OTHER PUBLICATIONS

Smith et al., "Principles And Practice Of Automatic Process Control", 1997, John Wiley & Sons, 2nd edition, pp. 1-9, 197, 222, 223, 225-227, 231-234.*

(Continued)

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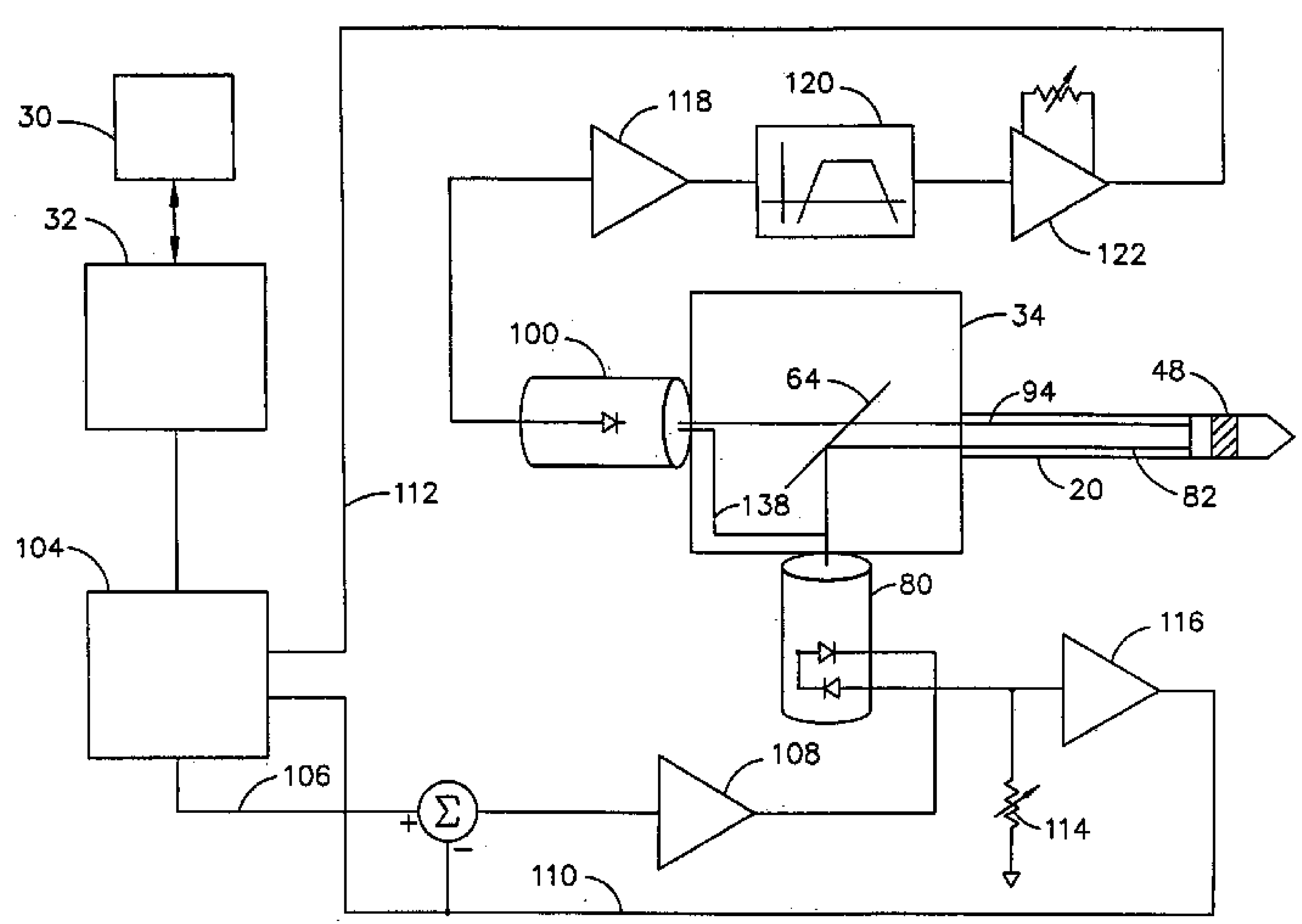
(57) **ABSTRACT**

A system and method of sensing temperature at an optical fiber tip, including the steps of positioning a slug of fluorescent material adjacent the optical fiber tip, providing an optical stimulus having a wavelength within a first predetermined range through at least one fiber optically linked to the optical fiber tip, wherein a desired optical fluorescent response having a wavelength within a second predetermined range from the fluorescent slug is generated, detecting a signal representative of the optical stimulus, detecting a signal representative of the optical fluorescent response, digitally processing the optical stimulus signal and the optical fluorescent response signal to determine a phase difference therebetween, and calculating a temperature for the optical fiber tip as a function of the phase difference. The phase difference between the optical stimulus signal and the optical fluorescent response signal may be determined directly or indirectly as a function of the phase difference between a reference signal and the optical stimulus signal and the phase difference between the reference signal and the optical fluorescent response signal.

**12 Claims, 10 Drawing Sheets**



U.S. PATENT DOCUMENTS

| | | | | |
|---|---|---|---|---|
| 4,437,772 | A | 3/1984 | Samulski | |
| RE31,832 | E | 2/1985 | Samulski | |
| 4,583,539 | A | 4/1986 | Karlin et al. | |
| 4,621,929 | A | 11/1986 | Phillips | |
| 4,652,143 | A | 3/1987 | Wickersheim et al. | |
| 4,663,520 | A | 5/1987 | Tanaka et al. | |
| 4,675,529 | A | 6/1987 | Kushida | |
| 4,695,697 | A * | 9/1987 | Kosa | 606/12 |
| 4,700,064 | A | 10/1987 | Fujita | |
| 4,703,175 | A | 10/1987 | Salour et al. | |
| 4,799,767 | A | 1/1989 | Woodruff | |
| 4,845,647 | A * | 7/1989 | Dils et al. | 374/131 |
| 4,864,098 | A | 9/1989 | Basanese et al. | |
| 4,895,156 | A * | 1/1990 | Schulze | 374/161 |
| 4,911,711 | A | 3/1990 | Telfair et al. | |
| 4,932,934 | A * | 6/1990 | Dougherty et al. | 604/21 |
| 4,946,256 | A | 8/1990 | Woodruff | |
| 4,994,059 | A * | 2/1991 | Kosa et al. | 606/12 |
| 5,032,005 | A | 7/1991 | Woodruff | |
| 5,107,445 | A | 4/1992 | Jensen et al. | |
| 5,124,993 | A | 6/1992 | Braunlich et al. | |
| 5,153,607 | A | 10/1992 | Ichinokawa | |
| 5,211,480 | A * | 5/1993 | Thomas et al. | 374/161 |
| 5,222,810 | A * | 6/1993 | Kleinerman | 374/161 |
| 5,232,285 | A | 8/1993 | Mannik | |
| 5,323,269 | A | 6/1994 | Walker et al. | |
| 5,351,268 | A * | 9/1994 | Jensen et al. | 374/131 |
| 5,364,391 | A | 11/1994 | Konwitz | |
| 5,473,428 | A * | 12/1995 | Lee et al. | 374/131 |
| 5,499,313 | A | 3/1996 | Kleinerman | |
| 5,579,773 | A | 12/1996 | Vo-Dinh et al. | |
| 5,596,590 | A | 1/1997 | de Ruyter et al. | |
| 5,684,590 | A * | 11/1997 | Sanders et al. | 372/32 |
| 5,754,717 | A | 5/1998 | Esch | |
| 5,779,696 | A * | 7/1998 | Berry et al. | 606/10 |
| 5,798,518 | A | 8/1998 | Coleman et al. | |
| 5,891,394 | A | 4/1999 | Drocourt et al. | |
| 5,928,222 | A * | 7/1999 | Kleinerman | 606/12 |
| 5,968,036 | A * | 10/1999 | Goodman et al. | 606/12 |
| 6,021,151 | A | 2/2000 | Eguchi | |
| 6,045,259 | A | 4/2000 | Djeu | |
| 6,055,451 | A | 4/2000 | Bambot et al. | |
| 6,086,250 | A | 7/2000 | Rouhet et al. | |
| 6,095,982 | A | 8/2000 | Richards-Kortum et al. | |
| 6,124,597 | A | 9/2000 | Shehada et al. | |
| 6,174,291 | B1 | 1/2001 | McMahon et al. | |
| 6,231,568 | B1 | 5/2001 | Loeb et al. | |
| 6,370,171 | B1 * | 4/2002 | Horn et al. | 372/34 |
| 6,475,210 | B1 | 11/2002 | Phelps et al. | |
| 6,537,269 | B1 | 3/2003 | Abe | |
| 6,567,438 | B1 * | 5/2003 | Lin | 372/34 |
| 6,575,962 | B1 | 6/2003 | Hohla | |
| 6,775,315 | B1 * | 8/2004 | Nield et al. | 606/12 |
| 2002/0136247 | A1 | 9/2002 | Ikeda et al. | |

FOREIGN PATENT DOCUMENTS

| | | |
|---|---|---|
| JP | 600 35230 | 2/1985 |
| JP | 9-122963 A | 5/1997 |
| RU | 1267341 A1 | 10/1986 |

OTHER PUBLICATIONS

Smith et al., "Principles And Practice Of Automatic Process Control", 1997, John Wiley & Sons, 2nd edition, pp. 241-243.*

EPO Search Report dated Dec. 16, 2004 for corresponding European Patent Application No. EP 02 25 3974.

EPO Search Report dated Nov. 9, 2004 for corresponding European Patent Application No. EP 02 25 3972.


* cited by examiner

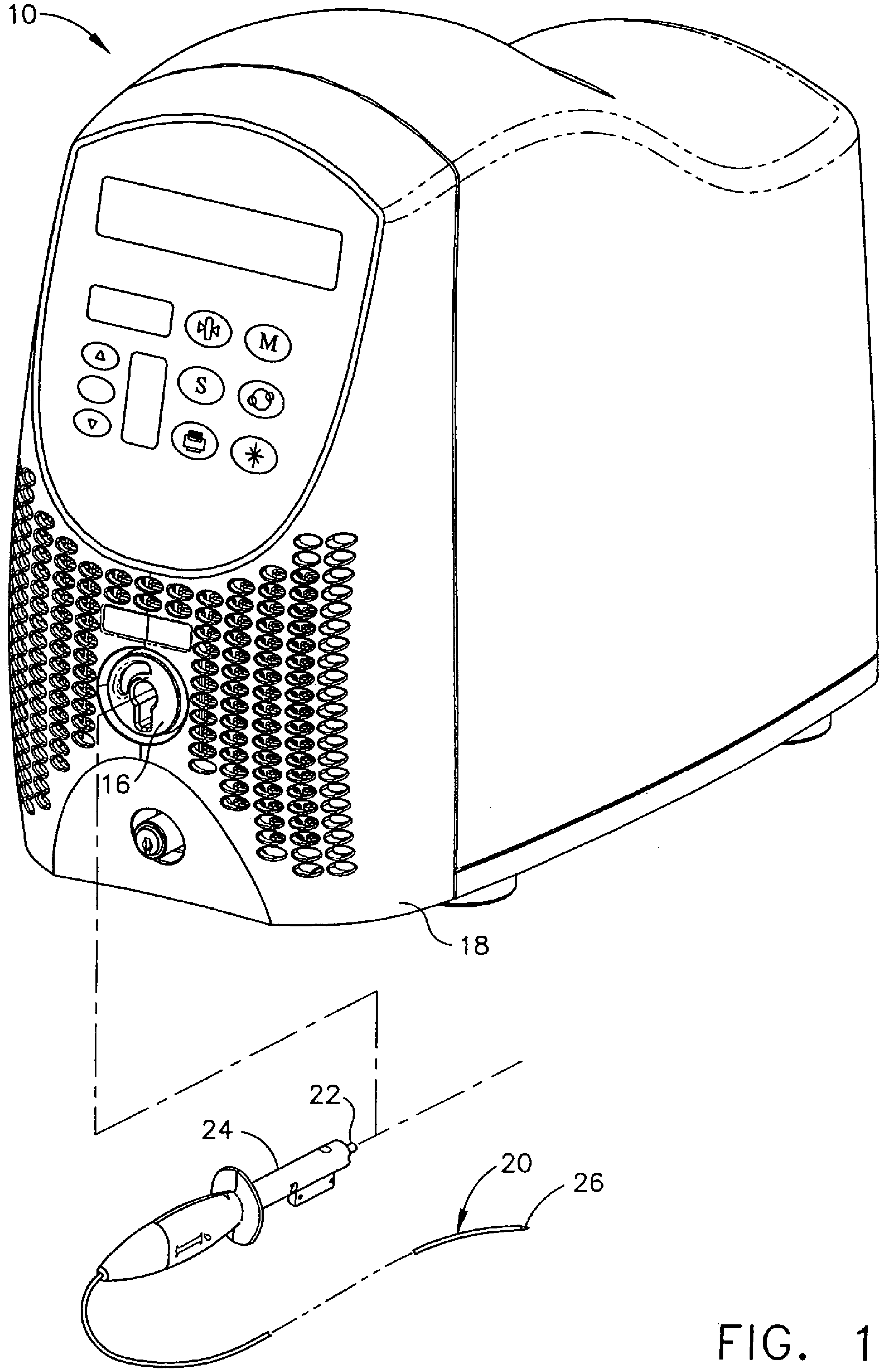



FIG. 1

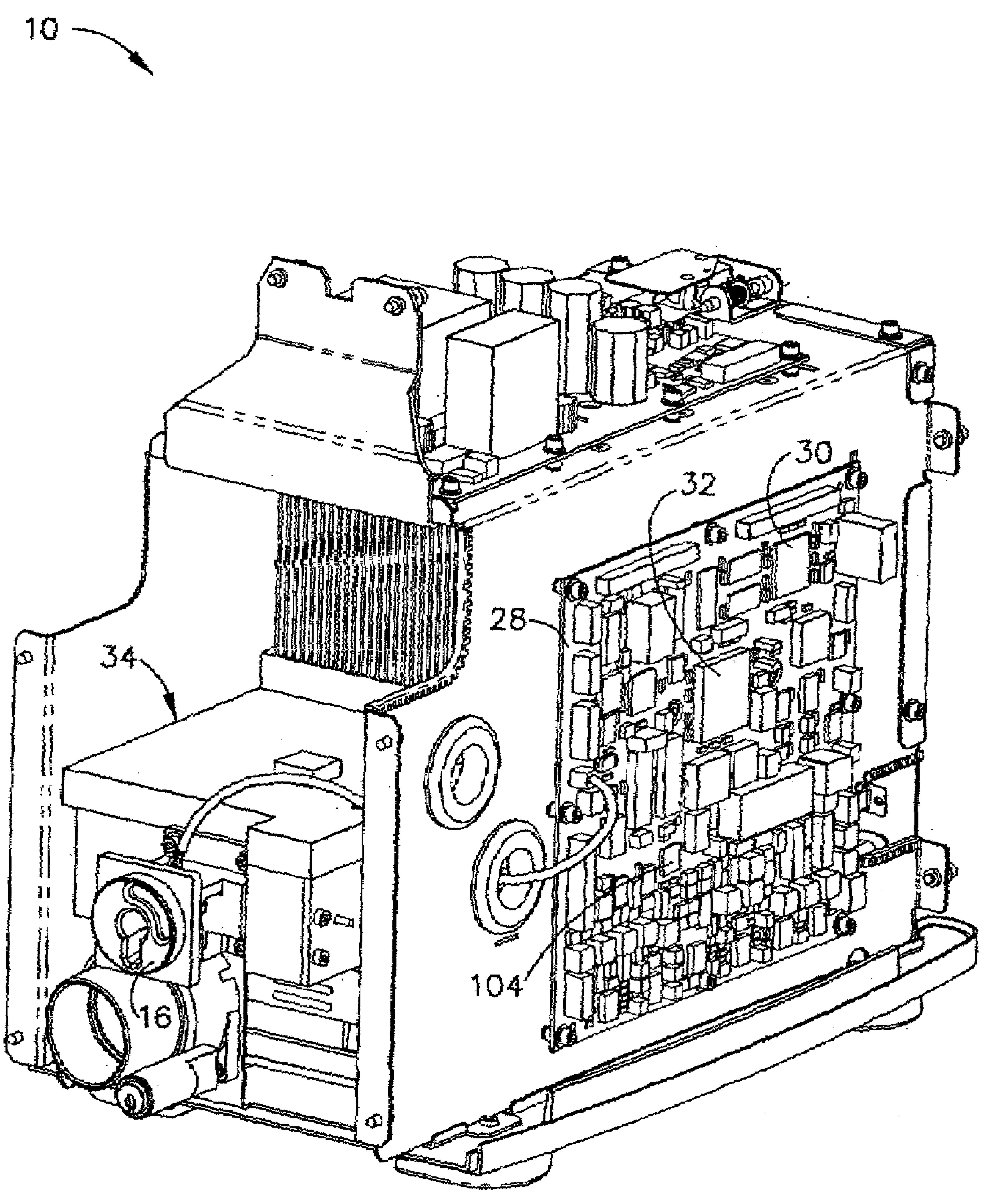



FIG. 2

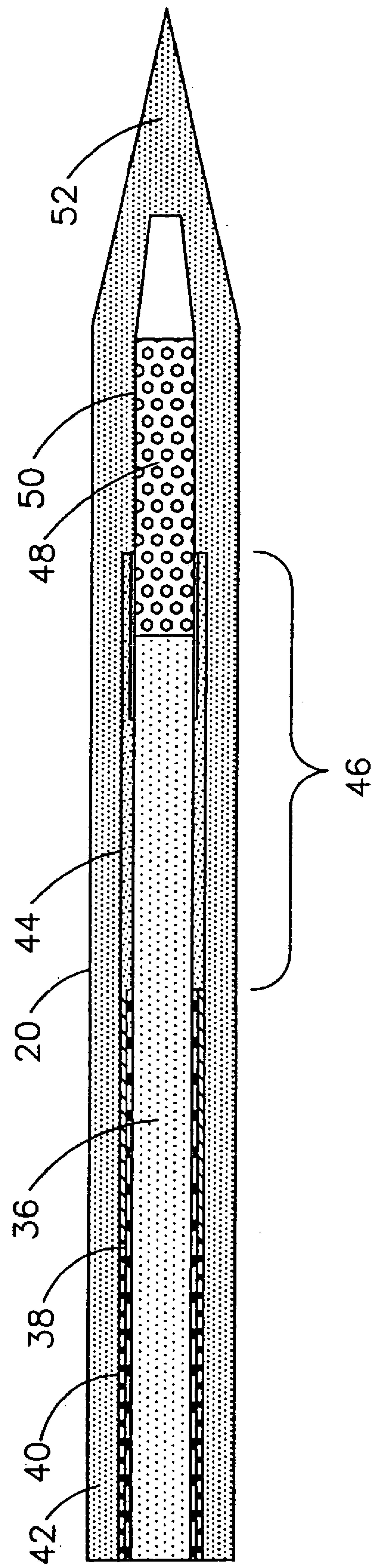



FIG. 3

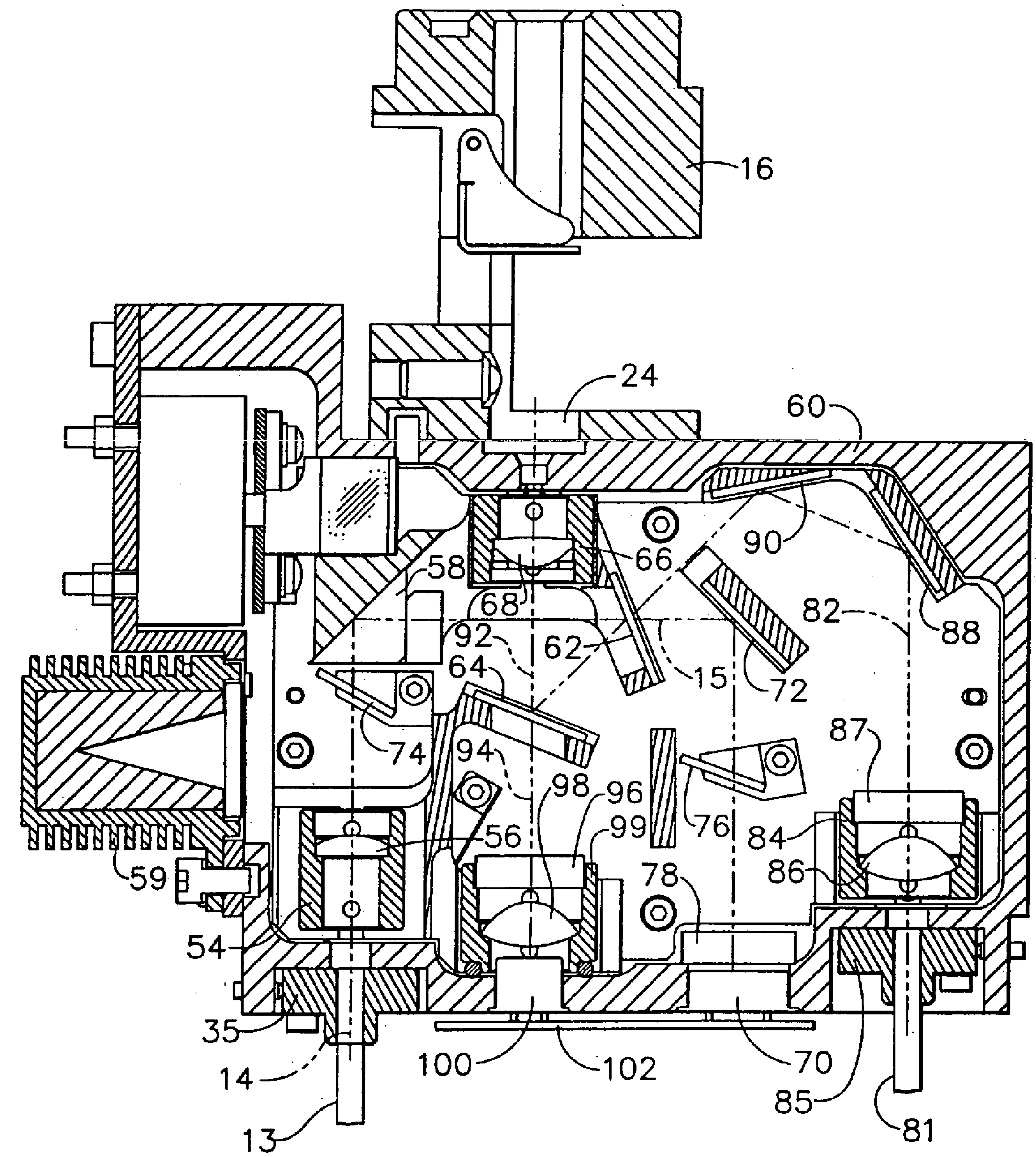

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FIG. 4

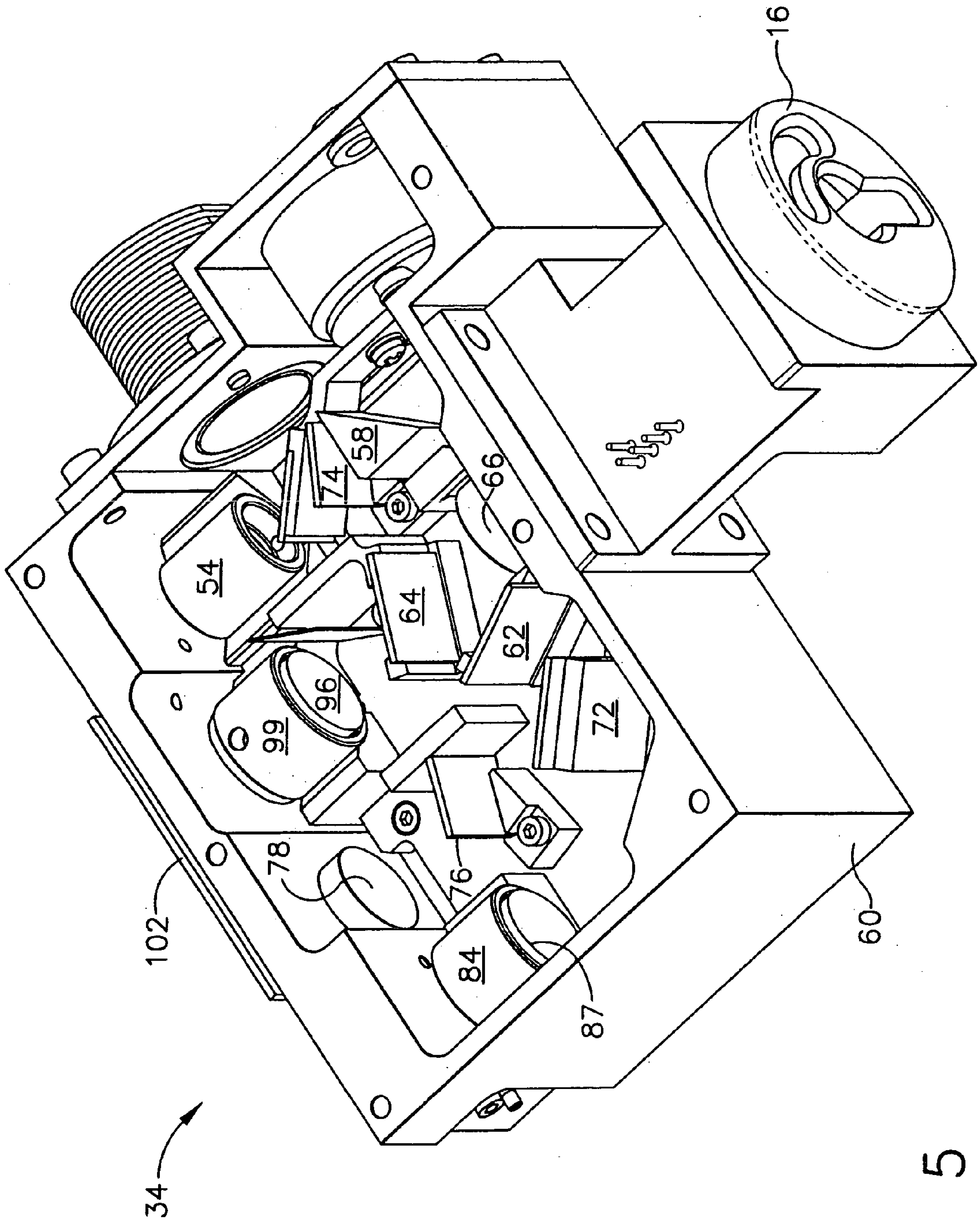


FIG. 5

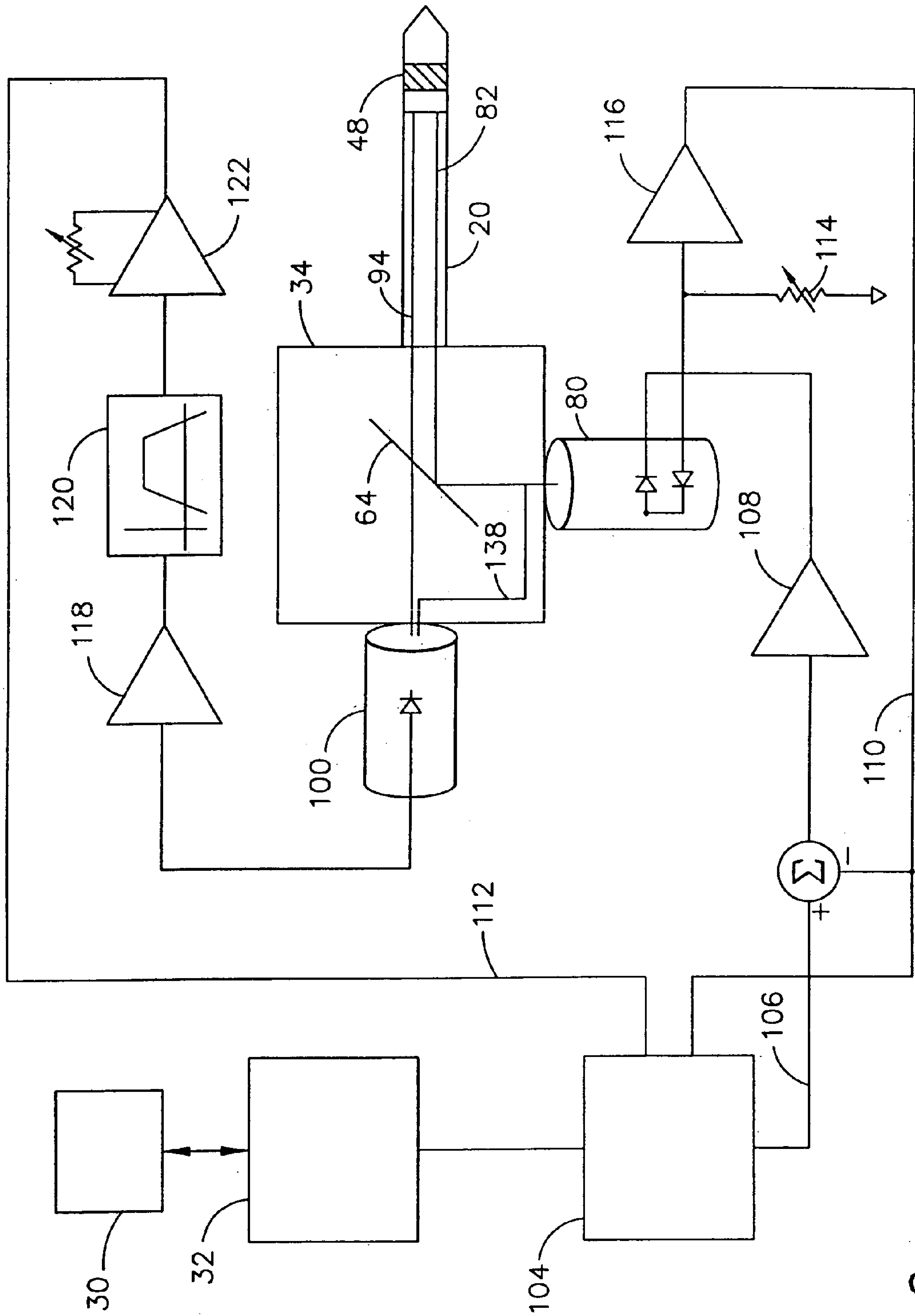
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FIG. 6

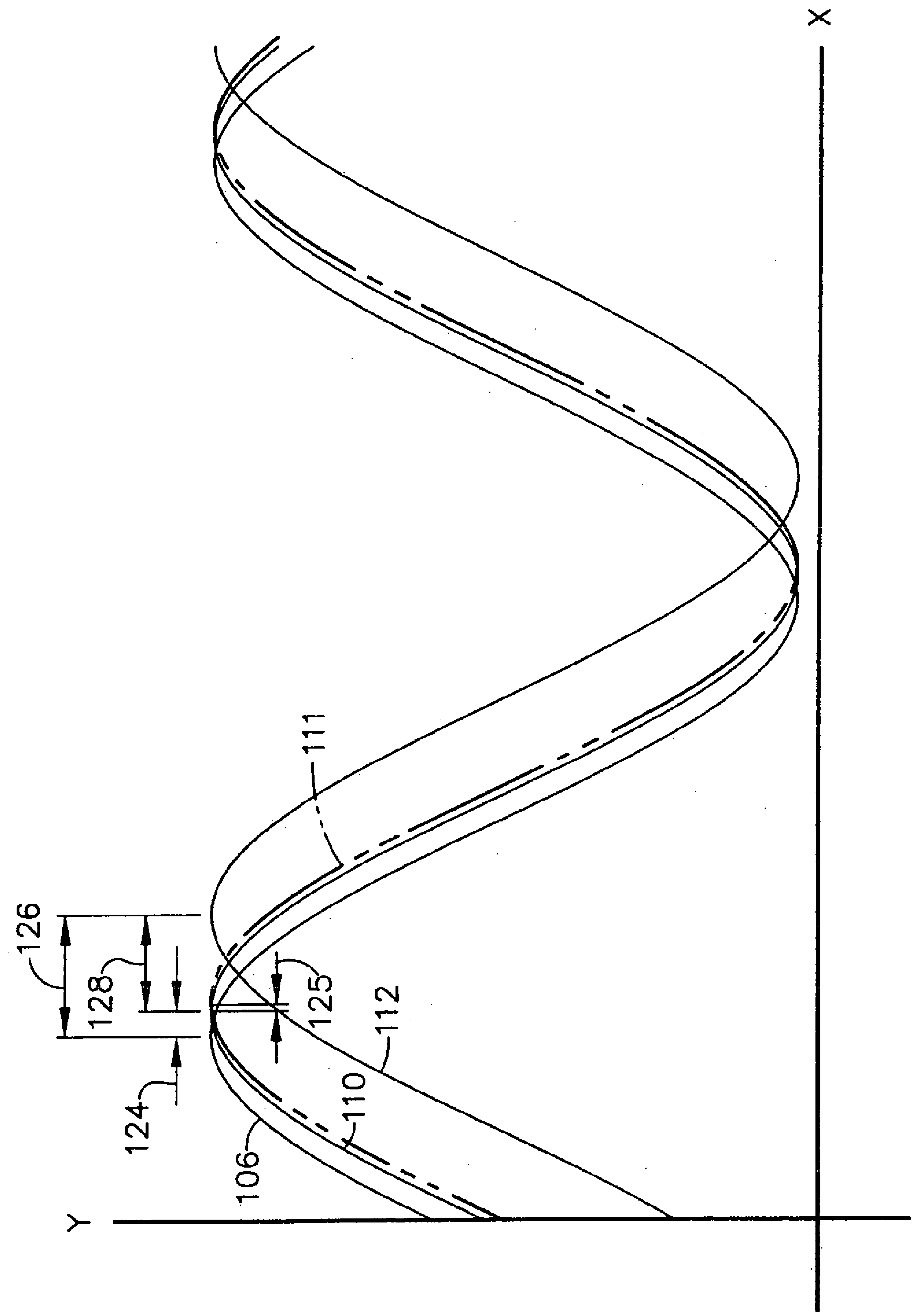


FIG. 7

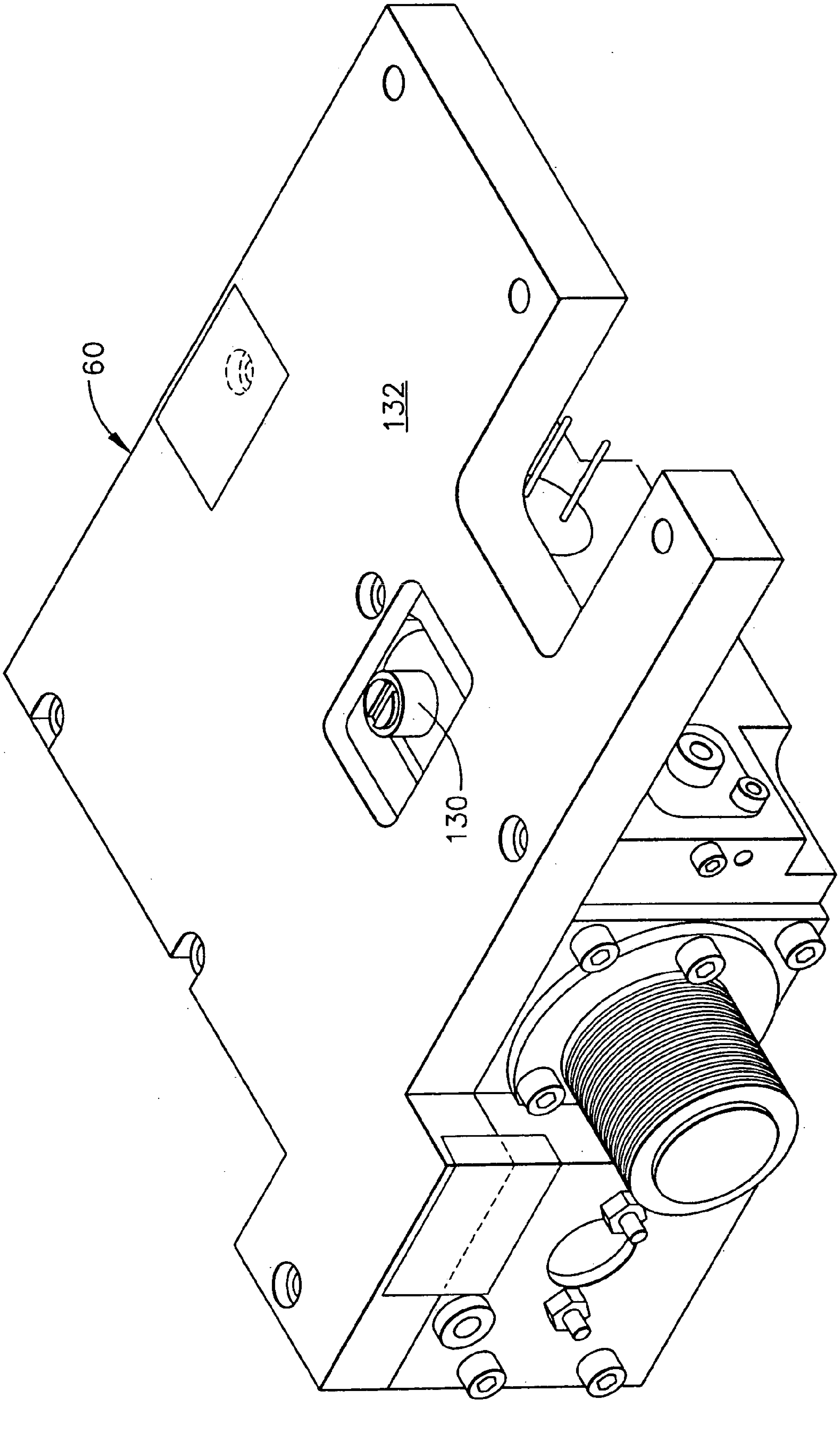


FIG. 8

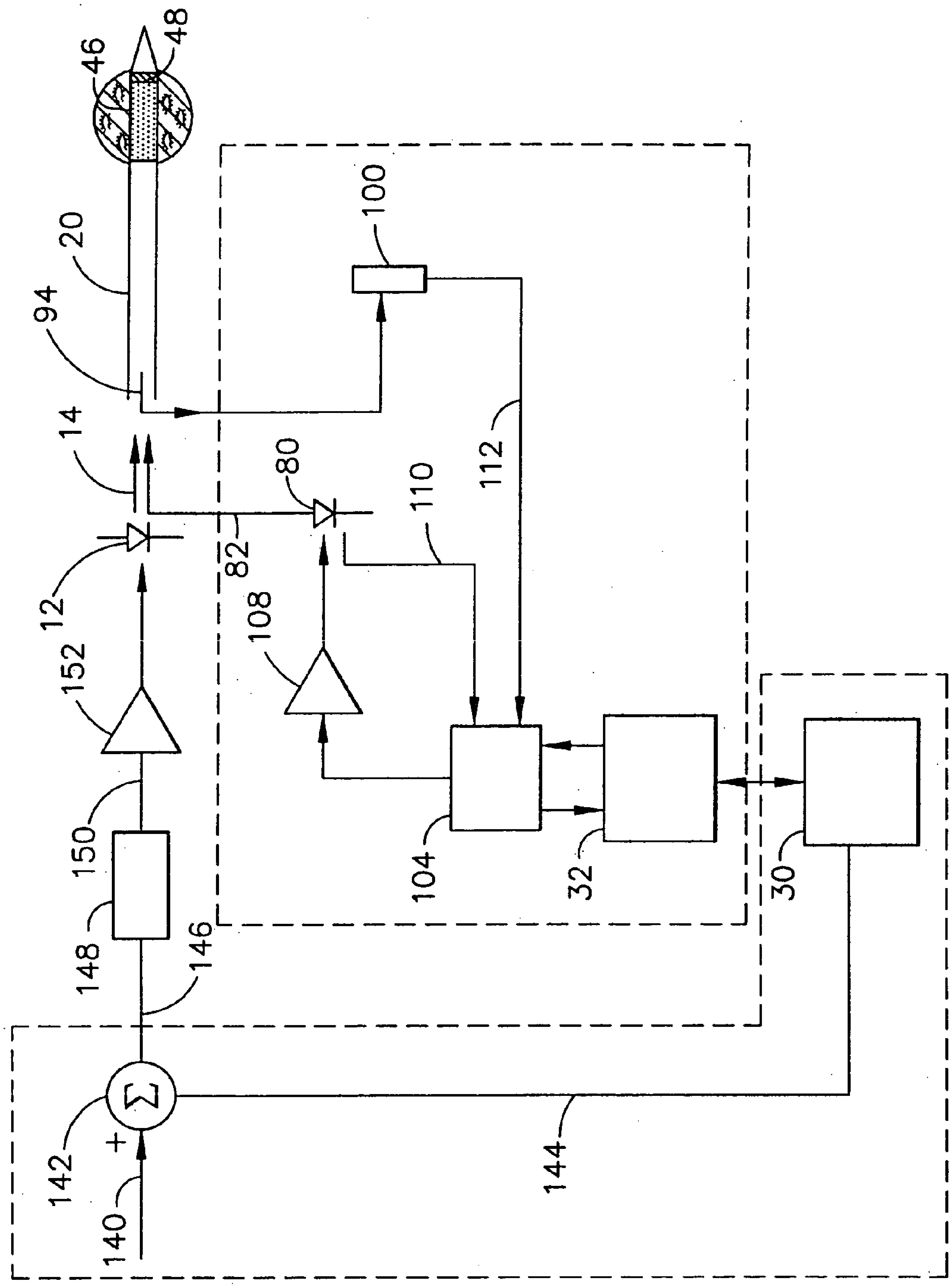
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FIG. 9

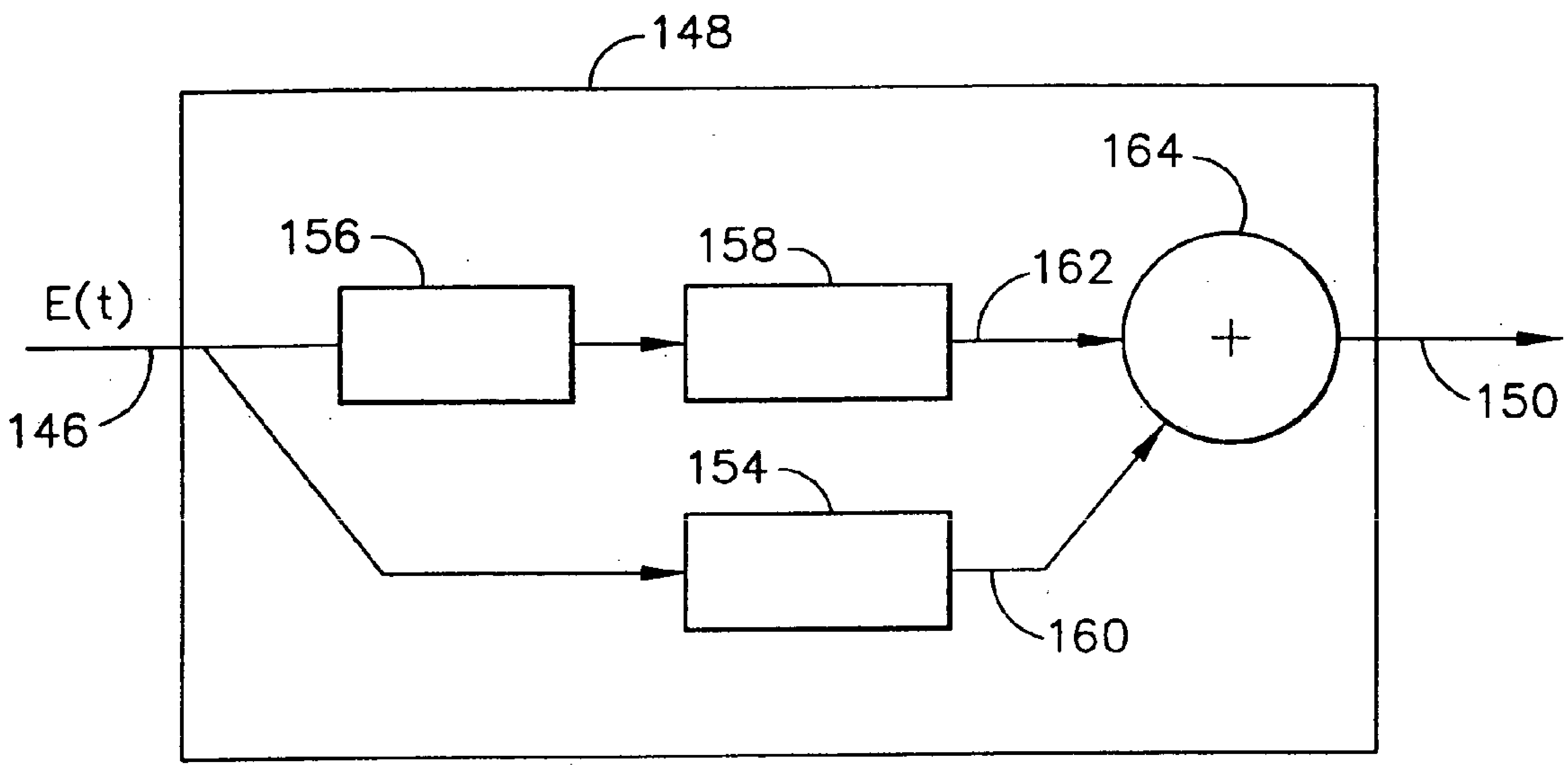


FIG. 10

# SYSTEM AND METHOD OF MEASURING AND CONTROLLING TEMPERATURE OF OPTICAL FIBER TIP IN A LASER SYSTEM

## CROSS REFERENCE TO RELATED APPLICATIONS

This divisional patent application claims priority to and incorporates by reference U.S. patent application Ser. No. 09/906,535 filed Jul. 16, 2001, now U.S. Pat. No. 6,796,710, in the names of David Yates et al., which claims priority to Provisional Application 60/296,783 filed Jun. 8, 2001.

## BACKGROUND OF THE INVENTION

The present invention relates to a laser system for transferring energy to tissue during medical treatment procedures and, more particularly, to a system and method of measuring and controlling temperature of an optical fiber tip for the laser treatment system during operation.

It is well known that energy generators in the form of lasers have been utilized to treat many disease states, including cancer, tumors, and benign prostatic hyperplasia (BPH). During the course of such treatments, one parameter which has great importance is the temperature of the tissue being treated. For example, the current recommendation for forming lesions in the prostate as a treatment for BPH is to heat a small volume of tissue to 85° C. for approximately three minutes. It will be appreciated that heating the tissue at a lesser temperature has the effect of incomplete lesion formation, while heating the tissue at a higher temperature can cause excessive tissue damage. Accordingly, the ability to accurately measure the temperature of the optical fiber tip during treatment, as well as control the power output of the laser to maintain the temperature at a desired level, is of primary concern.

It will be understood that there are several known ways of performing the temperature monitoring function for a laser system. One approach has been utilized in a laser treatment system known as the "Indigo 830e Laseroptic Treatment System" manufactured by Ethicon EndoSurgery, Inc. of Cincinnati, Ohio, which is also the assignee of the present invention. This approach involves relying upon the temperature dependence of the fluorescent response of a slug of material at the fiber tip to an optical stimulus. More specifically, a pulse of pump energy causes a fluorescence pulse in an alexandrite slug which is delayed by a time interval corresponding to a temperature of the material. By providing the stimulus signal in the form of a sinusoid, the response signal is likewise a sinusoid and the temperature is related to the phase shift or difference therebetween.

The signals which are compared in the 830e laser treatment system are the actual response or fluorescent signal from the alexandrite and a pair of timing signals (shifted 0° and 90° in phase) which are programmed in its electronics. In this way, digital timing signals are used to strip phase information from the response signal. It has been found, however, that several adjustments and calibrations are required under this approach due to the chain of amplifiers and filters involved. This not only adds complexity and cost to the set-up and maintenance of such systems, but creates an inherent variability between each laser treatment system that must be accommodated during manufacture and service.

Accordingly, it would be desirable for a system and method to be developed in which temperature of an optical fiber tip used with a laser device during treatment is able to be measured and controlled in a manner which minimizes the adjustments and calibrations required, improves the stability and repeatability between laser systems, and reduces complexity and cost.



## BRIEF SUMMARY OF THE INVENTION

In accordance with one aspect of the present invention, a method of sensing temperature at an optical fiber tip is disclosed as including the steps of positioning a slug of fluorescent material adjacent the optical fiber tip, providing an optical stimulus having a wavelength within a first predetermined range through at least one fiber optically linked to the optical fiber tip, wherein a desired optical fluorescent response having a wavelength within a second predetermined range from the fluorescent slug is generated, detecting a signal representative of the optical stimulus, detecting a signal representative of the optical fluorescent response, digitally processing the optical stimulus signal and the optical fluorescent response signal to determine a phase difference therebetween, and calculating a temperature for the optical fiber tip as a function of the phase difference. The phase difference between the optical stimulus signal and the optical fluorescent response signal may be determined directly or indirectly as a function of the phase difference between a reference signal and the optical stimulus signal and the phase difference between the reference signal and the optical fluorescent response signal.

In accordance with a second aspect of the present invention, a laser treatment system is disclosed as including a laser for providing a laser beam having a wavelength within a first predetermined range, at least one optical fiber having a first end in communication with the laser beam and a second end through which the laser beam is transmitted, a slug of fluorescent material positioned adjacent the second end of the optical fiber, a light source for providing an optical stimulus having a wavelength within a second predetermined range to the fluorescent slug, wherein a desired optical fluorescent response having a wavelength within a third predetermined range from the fluorescent slug is generated, a detector for detecting the optical fluorescent response, a device for receiving a first signal representative of the optical stimulus and a second signal representative of the optical fluorescent response, and a processor for determining a phase difference between the first and second signals, wherein the temperature of the optical fiber second end is determined as a function of the phase difference.

In accordance with a third aspect of the invention, an optical thermometry system is disclosed as including an optical fiber having a first end for receiving light and a second end for transmitting light, a slug of fluorescent material positioned adjacent the optical fiber second end, a light source for providing an optical stimulus through the optical fiber to the fluorescent slug in order to generate a desired optical fluorescent response therefrom, a detector for detecting the optical fluorescent response, a device for receiving a first signal representative of the optical stimulus and a second signal representative of the optical fluorescent response, and a processor to determine the phase difference between the first and second signals.

In accordance with a fourth aspect of the invention, a method of maintaining temperature of an optical fiber tip in a laser system within a specified range is disclosed as including the steps of positioning a slug of fluorescent material adjacent the optical fiber tip, providing an optical stimulus through at least one fiber optically linked to the optical fiber tip, wherein a desired optical fluorescent response from the fluorescent slug is generated, detecting a signal representative of the optical stimulus, detecting a signal representative of the optical fluorescent response, digitally processing the optical stimulus signal and the optical fluorescent response signal to determine a temperature for the optical fiber tip as a function of a phase difference therebetween, comparing the determined temperature for the optical fiber tip to the specified range, and modifying power output of the laser system as necessary to maintain temperature of the optical fiber tip within the specified range.

In accordance with a fifth aspect of the invention, a method of maintaining temperature of an optical fiber tip in a laser system at a desired temperature is disclosed as including the steps of processing specified light signals to determine a temperature for the optical fiber tip as a function thereof, comparing the determined temperature for the optical fiber tip to the desired temperature, generating an error signal as a function of any difference between the determined temperature and the desired temperature, and controlling power output to a laser diode of the laser system in accordance with the error signal.

In accordance with a sixth aspect of the invention, a system for maintaining temperature of an optical fiber tip in a laser system at a desired temperature is disclosed, wherein the laser system includes a laser diode for providing a laser beam to the optical fiber tip. The system includes a processor for determining a temperature for the optical fiber tip as a function of specified light signals detected in the laser system, a power amplifier for supplying power to the laser-diode, and a controller for providing a power output signal to the power amplifier, where the controller contains an algorithm for calculating the power output signal which is a function of an error signal generated by a comparison of the determined temperature and the desired temperature.

## BRIEF DESCRIPTION OF THE DRAWINGS

While the specification concludes with claims particularly pointing out and distinctly claiming the present invention, it is believed that the same will be better understood from the following description taken in conjunction with the accompanying drawings in which:

FIG. **1** is an isometric view of the laser treatment system of the present invention;

FIG. **2** is an isometric view of the laser treatment system depicted in FIG. **1**, where the housing has been removed to enable viewing of a controller board and the exterior of an optical bench therein;

FIG. **3** is an enlarged, partial section view of an optical fiber utilized with the laser treatment system shown generally in FIG. **1**;

FIG. **4** is a section view of the optical bench depicted in FIG. **2**, where the steering optics therein are positioned so as to allow a pair of laser beams to pass through the optical bench and into the optical fiber;

FIG. **5** is an isometric view of the optical bench depicted in FIGS. **2** and **4**, where a connect block and a sensor board are shown as interfacing therewith;

FIG. **6** is a circuit diagram of an optical thermometry system utilized by the laser treatment system depicted in FIG. **1** in accordance with the present invention;

FIG. **7** is a timing diagram of the reference, stimulus, response and calibrating signals depicted in FIG. **6**;

FIG. **8** is a top view of the optical bench depicted in FIGS. **2**, **4** and **5**;

FIG. **9** is a schematic block diagram of circuitry in the laser treatment system utilized to maintain a desired temperature of the optical fiber tip in accordance with the present invention; and,

FIG. **10** is a schematic block diagram of a controller utilized with the main processor shown in FIG. **9** to maintain the optical fiber within a desired temperature range.

## DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings in detail, wherein identical numerals indicate the same elements throughout the figures, FIG. **1** depicts a laser treatment system **10** for transferring energy to human tissue by means of light from an optical fiber **20**. A first laser diode **12** is provided in laser treatment system **10** (see FIG. **9**) to produce a first laser beam **14** having a predetermined power (preferably in a range of approximately 2–20 watts) and a predetermined wavelength (preferably in a range of approximately 800–850 nanometers) useful for the medical treatment of disease. As further seen in FIG. **1**, a connect block **16** is located within a front portion of a housing **18** for laser treatment system **10**. Connect block **16** assists first laser beam **14** in being optically linked with a first end **22** of optical fiber **20** via a connector **24** so that first laser beam **14** can be transmitted from a second end (or tip) **26** of optical fiber **20**.

FIG. **2** depicts laser treatment system **10** with housing **18** removed so as to expose a controller board **28**. It will be appreciated that, among other components, controller board **28** includes a main processor **30** which receives and processes electronic signals to control the operation of laser treatment system **10**. It is preferred that a digital signal processor **32** be provided on controller board **28** solely to calculate the phase difference between signals (as explained in greater detail hereinbelow). Accordingly, digital signal processor **32** is serially interfaced with main processor **30**, which also functions to process signals relating to such phase difference in order to determine the temperature of optical fiber tip **26**. It will be appreciated, then, that main processor **30** and digital signal processor **32** work in concert while in the appropriate laser operating mode to assure that the necessary power is provided to laser diode **12** so that optical fiber tip **26** is maintained at the desired temperature during treatment. Laser treatment system **10** also includes an optical bench, identified generally by reference numeral **34**, in order to direct first laser beam **14** into optical communication with optical fiber first end **22** during operation.

FIG. **3** depicts a partial section view of optical fiber **20**, which preferably is constructed in accordance with a patent application entitled "Optical Fiber Including A Diffuser Portion And Continuous Sleeve For The Transmission Of Light," Ser. No. 09/785,571, owned by the assignee of the present invention and hereby incorporated by reference. As seen in FIG. **3**, a central silica core **36** is preferably provided and includes a circumferential fluoropolymer cladding **38** and an outer buffer layer **40** (e.g., Tefzel) therearound. It will be understood that cladding **38** and outer buffer layer **40** each provide mechanical support to core **36** and have a lower index of refraction than core **36**. In this way, cladding **38** and outer buffer layer are able to block light from emerging out of core **36**. Optical fiber **20** further includes a sleeve **42**, preferably made of perflouroalkoxy (PFA) compounded with barium sulfate particles, which is optically and mechanically coupled to core **36** by a layer **44** of UV curable optical adhesive. This is best seen in a diffuser portion **46** of optical fiber **20**, where cladding **38** and outer buffer layer **40** have been removed so that light from first laser beam **14** transmitted through core **36** may be conducted from adhesive layer **44** through sleeve **42** and scattered into tissue during a medical treatment.

It will further be seen that a slug **48** of fluorescent material is positioned within an annulus **50** adjacent a downstream end of diffuser portion **46** so that any light from first laser beam **14** not exiting diffuser portion **46** exits through the end of core **36** and is scattered and reflected back into core **36**. Fluorescent slug **48** also functions as an optical temperature sensor and preferably is within a class of materials consisting of chromium-doped garnets (e.g., alexandrite, ruby, and emerald), semiconductor-doped glasses (e.g., Schott RG 665 filter glass manufactured and sold by Schott Glass Co. of Yonkers, N.Y.), phosphors, or other temperature dependent fluorescent materials. In this way, fluorescent slug **48** is able to receive an optical stimulus from a light source having a first wavelength and generate an optical fluorescent response at a second wavelength, where the wavelength of the optical stimulus and the optical fluorescent response are different from that of first laser beam **14**. In this regard, it is preferred that fluorescent slug **48** be substantially transparent to the wavelength of first laser beam **14** from laser diode **12** so as not to affect its use in treating tissue. A penetrating tip **52** is then attached to annulus **50** in order to assist in medical treatments.

Turning to optical bench **34**, it will be seen from FIGS. **4** and **5** that the path of first laser beam **14** enters optical bench **34** from an optical fiber **13** in optical communication with first laser diode **12**. Optical fiber **13** is positioned within a connector **35** in optical bench **34** to assure proper alignment. First laser beam **14** is transmitted through a beam collimator **54** containing a lens **56** and is preferably directed toward a total internal reflection (TIR) prism **58** mounted to a housing **60** for optical bench **34**. First laser beam **14** preferably reflects off TIR prism **58** and is received by a first beamsplitter **62**, which reflects first laser beam **14** toward a second beamsplitter **64**. First laser beam **14** is then reflected from second beamsplitter **64** through an output beam lens assembly **66** and an output lens **68** therein so as to place first laser beam **14** in optical communication with optical fiber first end **22** via connector **24**. It will be appreciated that a small percentage of first laser beam **14** (identified by reference numeral **15**) is preferably transmitted by first beamsplitter **62** to a laser power detector **70** by means of a turning mirror **72** so that the power output of first laser beam **14** can be monitored. Further explanation of first beamsplitter **62**, laser power detector **70**, and laser beam **15** is provided in a related patent application filed concurrently herewith entitled "Apparatus And Method Of Monitoring And Controlling Power Output Of A Laser System," having Ser. No. 09/877,275 which is owned by the assignee of the present invention and hereby incorporated by reference. Of course, various filters may be employed to better isolate and attenuate the wavelength of light provided by first laser beam **14**, as exemplified by filter **74**, correction filter **76**, and neutral density filter **78**.

Similarly, a second laser diode **80** (see FIG. **9**) preferably provides a second laser beam **82**, also known herein as a marker laser beam, to optical bench **34** by means of an optical fiber **81**. Optical fiber **81** is positioned within a connector **85** in optical bench **34** to assure proper alignment. Second laser beam **82** is transmitted through a marker beam collimator **84**, a marker lens **86**, and a marker filter **87** attached to optical bench housing **60**. Marker laser beam **82** preferably has a predetermined power (preferably in a range of approximately 0.5–2 milliwatts) and a predetermined wavelength (preferably in a range of approximately 600–650 nanometers). It will be appreciated that marker laser beam **82**, which is preferably time modulated as a sinusoidal signal, is used as the light source to optically stimulate fluorescent slug **48** in optical fiber **20** so as to generate a desired optical fluorescent response therefrom. In order to place marker laser beam **82** in optical communication with optical fiber first end **22** via connector **24**, it is directed toward a first laser turning mirror **88** which reflects it to a second laser turning mirror **90**. Marker laser beam **82** then impacts first beamsplitter **62**, which transmits most of marker laser beam **82** (as a function of its wavelength) so that it passes therethrough to second beamsplitter **64**. Marker laser beam **82** then reflects off second beamsplitter **64** and through output beam lens assembly **66** and output lens **68**. Accordingly, both first (treatment) laser beam **14** and second (marker) laser beam **82** are routed from first beamsplitter **62** to second beamsplitter **64**, as indicated by reference numeral **92**, into first end **22** of optical fiber **20** during normal operation of laser treatment system **10**.

It will be appreciated that marker laser beam **82** provides an optical stimulus to fluorescent slug **48**, which absorbs the energy of marker laser beam **82** and fluoresces in response thereto. The time delay from stimulation of fluorescent slug **48** by marker laser beam **82** to the fluorescence of fluorescent slug **48** is a function of the temperature of optical fiber second end **26** and can be measured and used to calculate such temperature. The optical fluorescent response, indicated by reference numeral **94**, is transmitted back through optical fiber **20** and out optical fiber first end **22** into optical bench **34**. Optical fluorescent response **94** preferably has extremely low power (in a range of approximately 5–100 nanowatts) and has a preferred wavelength of approximately 680–780 nanometers. Optical fluorescent response **94** then passes through output lens **68** and output beam lens assembly **66** to second beamsplitter **64**. Second beamsplitter **64** is constructed so that optical fluorescent response **94** is transmitted therethrough to a signal filter set **96**, which functions to block most of any reflected marker and treatment light. The remaining signal, filtered to pass only the fluorescent and blackbody wavelengths, passes through a focussing lens **98** held together with signal filter set **96** in a signal optical assembly **99** and onto a fluorescence/blackbody detector **100**.

It will be seen that a sensor board **102** is provided adjacent to optical bench housing **60** so as to interface with fluorescence/blackbody detector **100** and laser power detector **70**. In particular, it will be appreciated that circuitry on sensor board **102** amplifies and conditions the outputs from detectors **70** and **100**. Sensor board **102** is also connected to and communicates with controller board **28** in order to calculate the temperature of optical fiber second end **26**, sense blackbody signals and measure the optical output power of first laser beam **14**.

In order to sense and maintain the temperature of optical fiber second end **22**, an optical thermometry system in accordance with the present invention is provided as part of laser treatment system **10**. More specifically, FIG. **6** depicts a device **104**, such as a coder/decoder (CODEC), located on controller board **28** as being utilized to provide a sinusoidal reference signal **106** (see FIG. **7**) to a marker drive **108** for second laserdiode **80** so that the optical stimulus provided by marker laser beam **82** and the optical fluorescent response **94** from fluorescent slug **48** are sinusoids having substantially the same frequency. Of course, device **104** includes the necessary digital-to-analog converter to provide marker drive **108** the appropriate signal.

It will be appreciated that device **104** also receives analog signals **110** and **112** which are representative of the optical stimulus from marker laser beam **82** and optical fluorescent response **94** from detector **100**. Device **104** also includes analog-to-digital converters therein for transforming signals **110** and **112**. Circuitry is provided on controller board **28** for controlling the power of second laser diode **80** and thus keep signal **110** substantially constant. More specifically, a potentiometer **114** and an amplifier **116** function to set the optical power of marker laser beam **82** and control the level for signal **110** within a specified range. Similarly, signal **94** is amplified and filtered by an amplifier **118** and a filter **120**, respectively, located on sensor board **102** to facilitate processing of signal **112** by digital signal processor **32**. A second amplifier **122** is also preferably located on controller board **28** and serves to further amplify the filtered signal prior to receipt by device **104**.

It will be appreciated that elements other than fluorescent slug **48** (i.e., amplifier **118**, filter **120**, and amplifier **122**) may influence optical fluorescent signal **112** and its phase shift **128** with respect to optical stimulus signal **110**. Phase shift **128** is depicted in the figures as the change in time between two sinusoids of the same frequency. Accordingly, a calibration scheme has been developed to calculate the effects on optical fluorescent signal **112**. In particular, it will be seen in FIG. **8** that a port **130** is provided in a top portion **132** of optical bench housing **60**. This permits an optical fiber to be inserted therein which is in optical communication with marker laser beam **82** via connector **24**. In this way, marker laser beam **82** is directed on detector **100** without passing through signal filter set **96** so that the inherent phase shift of the aforementioned elements can be measured and subtracted from optical fluorescent signal **112** (see calibrating signal **111** and the inherent phase shift with optical stimulus signal **110** denoted by reference numeral **125** in FIG. **7**). This is also depicted schematically in FIG. **6** by feedback loop **138** where optical stimulus signal **110** bypasses fluorescent slug **48** and is provided directly to detector **100**. In this way, operation of all laser treatment systems **10** can be normalized regardless of variability between components.

An alternative calibration scheme would be to provide an optical fiber plug-in including a fluorescent part therewith (not shown), where the fluorescent part has a very quick fluorescence at substantially the same wavelength as optical fluorescent signal **112** and can be inserted into connector **24** instead of optical fiber **20**. It will be appreciated that an exemplary fluorescent is available through Labsphere, Inc. of North Sutton, N.H. Accordingly, marker laser beam **82** is provided to the fluorescent and an optical fluorescent response signal is emitted therefrom to detector **100** as described above with respect to fluorescent slug **48**. This signal is then quantified and utilized to subtract out any inherent phase shift in optical fluorescent response signal **112** received by device **104**.

The phase difference processing of signals **110** and **112** is preferably performed by digital signal processor **32**, which then sends the appropriate signals to main processor **30** for calculation of the temperature for optical fiber second end **26** as a function of such phase (i.e., by means of a polynomial algorithm of at least the third order and preferably of the fifth order). Of course, such signals **110** and **112** will take into account the calibration of laser treatment system **10** and inherent phase shift **125** described hereinabove. While the phase difference between signals **110** and **112** may be determined directly, it has been found preferable to utilize reference signal **106** provided by device **104** to drive **108**. Accordingly, as seen in FIG. **7**, a first phase difference **124** between reference signal **106** and optical stimulus signal **110** and a second phase difference **126** between reference signal **106** and optical fluoroluminescent signal **112** is determined, with the difference between first and second phase differences **124** and **126** being equivalent to an overall phase difference **128** between optical stimulus signal **110** and optical fluorescent signal **112**.

Besides merely calculating the temperature of optical fiber second end **26**, however, laser treatment system **10** also functions to utilize such information in order to maintain a desired temperature there and in the adjacent tissue. This is accomplished by monitoring such temperature and providing the necessary power adjustments to first laser beam **14** as necessary. As seen in FIG. **9**, a temperature set point **140** indicative of the desired temperature is provided to a summing device **142**. A feedback signal **144** from main processor **30** is also provided to summing device **142** indicating the current sensed temperature of optical fiber second end **26**, whereby Error signal **146** does change sign and will be considered positive when sensed temperature **144** is less than desired temperature **140** and negative when sensed temperature **144** is greater than desired temperature **140**. It will be seen that error signal **146** is provided to a controller **148**, which, in turn, provides a signal **150** to a power amplifier **152** that adjusts the power to laser diode **12**. In the preferred embodiment, control of power for first laser beam **14** based on temperature set point **140** and feedback signal **146** is accomplished via software in main processor **30**.

More specifically, it will be seen from FIG. **10** that controller **148** preferably utilizes a proportional integral (PI) control algorithm which includes a proportional component and an integrator component. The proportional component is made up of error signal **146** being multiplied by a scaling factor $K_p$ indicated by box **154** and the integrator component involves error signal **146** (also shown mathematically as E(t)) being provided to an integrator **156** and multiplied by a scaling factor $K_i$ as shown in box **158**. It will be understood by those of ordinary skill in the art that scaling factors $K_p$ and $K_i$ are constants which are selected to provide a balance between response time, overshoot and accuracy of the final value of temperature, the dynamics of the tissue involved, and have units of watts/° C. Output signals **160** and **162** from the proportional component and integrator component, respectively, are then added in a summing device **164** to provide power signal **150**. Thus, power signal **150** can be represented mathematically by the following:

$$P(t)=K_p \times E(t)+K_i \int E(t)dt.$$

It will be appreciated that the integrator component, which sums all error from past performance of the control algorithm, is preferably utilized only when the sensed temperature **144** calculated by main processor **30** is within a defined control band (e.g., desired temperature **140** plus or minus 5° C.). Accordingly, if sensed temperature **144** is lower than the control band (i.e., less than desired temperature **140** minus 5° C.), then signal **150** from controller **148** provides for power amplifier **152** to supply maximum power (e.g., 15 Watts) to laser diode **12** so as to warm the tissue being treated. By contrast, if sensed temperature **144** is higher than the control band (i.e., more than desired temperature **140** plus 5° C.), then signal **150** from controller **148** provides for power amplifier **152** to supply minimum power (e.g., 0 Watts) to laser diode **12**. In this way, the tissue being treated is able to cool and return to a temperature within the control band. It has been learned that laser diode **12** may not reliably produce coherent laser output below approximately

2 Watts, so power to laser diode **12** can be momentarily turned off in the preferred embodiment to provide a power of less than 2 Watts. It will be noted, then, that the integrator component of the control algorithm has a greater effect as sensed temperature **144** gets closer to desired temperature **140** and is what gives the control algorithm the ability to drive error signal **146** to zero.

In order to prevent integrator wind-up and otherwise optimize system performance, it is preferred that the integrator component of controller **148** be preloaded or pre-charged upon recognition of a transition point at either end of the control band so that power signal **150** remains continuous for one iteration of the control algorithm. This can be backsolved from the aforementioned mathematical equation to be:

$$\int E(t)dt=P(t)-K_p/K_i\times E(t).$$

In this way, power oscillations are avoided during the transition into the lower end of the control band, for example, so that a smooth reduction in power signal **150** occurs accompanied by a sensed temperature **144** which slightly overshoots desired temperature **140** (but stays within the control band) and then is maintained at such desired temperature **140**. Thus, not only does operation of laser treatment system **10** become smoother, but the time to reach steady state at desired temperature **140** is reduced.

Having shown and described the preferred embodiment of the present invention, further adaptations of the system and method for measuring and controlling temperature of an optical fiber tip during treatment by the laser treatment system can be accomplished by appropriate modifications by one of ordinary skill in the art without departing from the scope of the invention.

What is claimed is:

**1**. A method of maintaining temperature of an optical fiber tip in a laser system at a desired temperature, comprising the following steps:

(a) processing an optical stimulus and an optical response to determine a temperature for said optical fiber tip as a function thereof;

(b) comparing said determined temperature for said optical fiber tip to said desired temperature;

(c) generating an error signal as a function of any difference between said determined temperature and said desired temperature; and

(d) controlling power output to a laserdiode of said laser system in accordance with said error signal;

wherein the method further comprises the step of determining whether said determined temperature is within a defined control band having an upper and lower limit; and wherein a maximum power output is provided to said laserdiode when said determined temperature is less than said lower limit.

**2**. The method of claim **1**, wherein a minimum power output is provided to said laserdiode when said determined temperature is greater than said upper limit for said control band.

**3**. The method of claim **1**, wherein said power output to said laserdiode is a function of a proportional component and an integrator component when said determined temperature is within said control band.

**4**. The method of claim **3**, said proportional component of said power output being the product of said error signal and a proportional scaling factor.

**5**. The method of claim **3**, said integrator component of said power output being the product of an integrator scaling factor and each said error signal integrated over time.

**6**. The method of claim **5**, wherein said integrator component is only utilized upon said determined temperature transitioning into said control band so that said power output to said laserdiode remains continuous during said transition.

**7**. A system for maintaining temperature of an optical fiber tip in a laser system at a desired temperature, said laser system including a laser diode for providing a laser beam to said optical fiber tip, comprising:

(a) a processor for determining a temperature by processing an optical stimulus and an optical response;

(b) a power amplifier for supplying power to said laser diode; and

(c) a controller for providing a power output signal to said power amplifier, said controller containing an algorithm for calculating said power output signal which is a function of an error signal generated by a comparison of said determined temperature and said desired temperature; wherein said controller provides a power output signal so that a maximum power is supplied to said laser diode by said power amplifier when said determined temperature is less than a lower limit of a defined control band for said desired temperature.

**8**. The system of claim **7**, wherein said controller provides a power output signal so that a minimum power is supplied to said laser diode by said power amplifier when said determined temperature is greater than an upper limit of a defined control band for said desired temperature.

**9**. The system of claim **7**, wherein said algorithm is a function of a proportional component and an integrator component when said determined temperature is within a defined control band for said desired temperature.

**10**. The system of claim **9**, said proportional component of said algorithm being a product of said error signal and a proportional scaling factor.

**11**. The system of claim **9**, said integrator component of said algorithm being a product of an integrator scaling factor and each said error signal integrated over time.

**12**. The system of claim **11**, wherein said integrator component is only utilized upon said determined temperature transitioning into said control band so that power supplied to said laser diode remains continuous during said transition.

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